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Test Results From a 37-mm Segmented-Chamber Bulk-Loaded Liquid Propellant Gun

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ARL-TR-871 September 1995

NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1995	Final, Jan 93 - Oct 94

4. TITLE AND SUBTITLE
Test Results From a 37-mm Segmented-Chamber Bulk-Loaded Liquid Propellant Gun

5. FUNDING NUMBERS
PR: 1L162618AH80

6. AUTHOR(S)
T. E. Rosenberger, I. C. Stobie, and J. D. Knapton

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Research Laboratory
ATTN: AMSRL-WT-PA
Aberdeen Proving Ground, MD 21005-5066

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-871

9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)

10.SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

A program was initiated at the U.S. Army Research Laboratory (ARL) to investigate the use of segmented-chamber configurations to control the ballistic variability in bulk-loaded liquid propellant guns (BLPG). A series of gun firings was performed in a 37-mm BLPG using OTTO II monopropellant. Results of these tests indicated that a radial igniter and solid propellant booster with various segmented-chamber concepts are favorable in controlling the combustion evolution and ballistic stability in this gun system. Subsequent 37-mm gun firings designed to investigate the feasibility of achieving the same results using a HAN-based propellant (XM46) were performed. Results of these tests indicated that XM46 is more difficult to ignite in this system than OTTO II monopropellant. This report describes the system configuration and test results which exploited segmented-chamber configurations to control the combustion evolution and ballistic stability in the 37-mm gun using OTTO II monopropellant. Test results using XM46 in the same configuration are presented and future plans are discussed.

14. SUBJECT TERMS	15. NUMBER OF PAGES
liquid propellant guns, interior ballistics, bulk loaded, segmented chamber	39
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

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ACKNOWLEDGEMENTS

The authors would like to thank Mr. Robert P. Kaste of the U.S. Army Research Laboratory (ARL) for his technical assistance in ballistics and mechanical engineering support. Much appreciation is also extended to Mr. James DeSpirito of the U.S. Army Research Laboratory and Mr. Robert Talley of Veritay Technology, Inc. for their many technical suggestions and for reviewing this report.

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1. INTRODUCTION

The Bulk-Loaded Liquid Propellant Gun (BLPG) concept remains attractive to today's Army because it offers the advantages of any liquid propellant (LP) system, including: improved efficiency in the logistics chain, decreased cost of propellant production, reduced system vulnerability, and an opportunity for higher charge loading densities (Morrison, Knapton, and Bulman 1988). Perhaps more importantly, it also adds mechanical simplicity when compared to the regenerative liquid propellant gun (RLPG) system (Pate and Magoon 1985; Mandzy et al. 1983; Magoon, Haberl, and Purtee 1989; Mandzy, Cushman, and Magoon 1987). However, the BLPG has a long history of performance variability, including numerous overpressures and system failures. The basic problem is that the combustion process depends on hydrodynamic instabilities rather than on a preformed propellant geometry to define burning surface. Morrison, Knapton, and Bulman (1988) found that small differences in ignition stimulus, initial ullage, or shot start pressure may influence these instabilities in such a way as to amplify their influence tremendously on the combustion process and the overall ballistic event. This reference gives an excellent historical overview of LP guns and summarizes the traditional understanding of the BLPG processes. In addition it offers an extensive bibliography of BLPG research.

One approach to overcome the traditional BLPG problem is to develop the methodology that reduces the amplification of the early instabilities and hence makes the system tolerant of minor, yet unavoidable, variations in initial conditions. To this end, a program was initiated at the Army Research Laboratory (ARL) to investigate the use of segmented-chamber configurations to control the ballistic variability in BLPGs. A series of gun firings were performed in a 37-mm BLPG using OTTO II monopropellant. Results of these tests indicate that a piston radial igniter and a solid propellant booster with various segmented-chamber concepts are favorable in controlling the combustion evolution and ballistic stability in this gun system. Subsequent 37-mm gun firings designed to investigate the feasibility of achieving the same results using a hydroxylammonium nitrate (HAN)-based propellant (XM46) were performed. Results of these tests indicated that XM46 (previously designated LGP 1846) is more difficult to ignite in this system than OTTO II monopropellant. This report describes the system configuration and test results that made use of segmented-chamber configurations to control the combustion evolution and ballistic stability in the 37-mm gun using OTTO II monopropellant. Test results using XM46 in the same configuration are also presented and future plans are discussed.

2. METHODOLOGY

A typical BLPG system has often been characterized in literature as consisting of a near-bore diameter cylindrical combustion chamber, a projectile seated at the forward end of the combustion chamber just inside the barrel, and an igniter at the breech. This classical BLPG configuration features the utmost in mechanical simplicity but offers few means to control and stabilize the ignition and combustion processes and the associated fluid dynamics and combustion instabilities characteristic of BLPGs (Comer, Shearer, and Jones 1963). Unlike the solid propellant combustion process in which the burning rate depends on a predefined propellant geometry to determine burning surface and progressivity, the ignition and combustion process of LP is initially characterized by the growth and geometry of an ignition bubble and combustion gas cavity (Comer 1976), analogous to the motion of a gas cavity in a gravitational field (Davies and Taylor 1950; Taylor 1950). After this cavity reaches the projectile base, an annulus of liquid remains on the chamber walls. Combustion gases flowing at high velocities through this annulus results in turbulent mixing of the liquid and gas at the inner surface of the annulus. This turbulent mixing is commonly referred to as the Helmholtz instability (Helmholtz 1868). These instabilities may grow and cause some of the liquid to break off and form droplets, which drastically changes the amount of surface area available for combustion, causing poor system repeatability. It has been experimentally demonstrated that small differences in ignition stimulus, initial ullage, or shot start pressure may influence these instabilities in such a way as to amplify their influence on the combustion process and the overall ballistic event (Morrison, Knapton, and Bulman 1988).

As mentioned in the introduction, a general approach to overcome the traditional BLPG instability problems is to develop a methodology to reduce the amplification of the early instabilities and hence make the system tolerant of minor, yet unavoidable, variations in initial conditions. The approach presented in this report is to segment the combustion chamber into several smaller subchambers in an effort to decrease the amplification of the instabilities, and thereby control ballistic variability in BLPGs. The premise for segmenting the combustion chamber is that random variations occurring in the subchambers will cancel, or at least not reinforce one another, significantly reducing the overall system sensitivity to minor variations in initial conditions. In addition, the added boundary conditions due to the many subchambers may provide needed preformed surface area to allow the propellant to burn more uniformly. This concept is based on a United States patent entitled "Combustion Sub-channels for

Bulk-Loaded Liquid," which asserts that "the gas and pressure produced in each sub-chamber will be ejected into the common volume located forward of their open ends and aft of the projectile base, where their individual contribution to the propelling pressure will be summed, and their variations averaged" (Puckett 1990). The patent was a conceptual one that offered no experimental data in support of the assertion. For comparison, various small-caliber BLPG systems have been developed ($\leq$7.62 mm) that exhibit acceptable performance and repeatability, but only for small firing groups under controlled laboratory conditons (Knapton, Stobie, and Comer 1976).

A study of literature yielded very little information concerning past attempts to experimentally explore the segmented-chamber concept. Redel Inc. (1956) briefly described an attempt to use a "four-holed honeycomb" in a 20-mm BLPG. The pressure-time curve exhibited the elimination of the traditional double hump, but they were unable to draw any conclusions from the single test. No further details or investigations were discussed. Gemershausen, Schmitt, and Reinelt (1986) discussed segmentation of the igniter cavity region, however, the combustion chamber was configured in the traditional BLPG fashion. As with the case of the 20-mm "honeycomb" chamber, no significant developments were noted. Based upon the apparent lack of a thorough evaluation of the concept, the ARL began an experimental program to investigate the assertion that segmenting the combustion chamber of a BLPG will control the variabilities in the ballistic process (Talley and Owczarczak 1992).

3. EXPERIMENTAL

3.1 Gun System. Testing of the segmented-chamber BLPG concept was performed in a 37-mm antitank gun, designated M3 in the Army inventory. A sketch of the gun chamber is shown in Figure 1. The chamber has a chambrage region as shown in the figure. The gun tube consists of 12 equally spaced, right-hand lead grooves with 48 calibers of travel. This weapon was chosen because it offered sufficient chamber volume to allow effective segmentation while at the same time facilitating testing with a reasonable projectile mass and propelling-charge-to-mass ratio (projectile mass = 447 g, C/M = 0.33). In addition, it was also convenient because it had a sliding breech mechanism that allowed easy loading of the round. However, one major drawback was the maximum pressure envelope safety rating of 450 MPa, which was based on a soldier standing behind the weapon and pulling a lanyard. Given the ratio of the outside-to-inside diameter of the combustion chamber, it was decided that the pressure envelope could be extended to nearly 550 MPa without damage to the weapon. Since these studies were to be performed at a relatively low performance level and were designed to establish the merits of the segmented-chamber concept, the investigators deemed the fixture acceptable for testing.

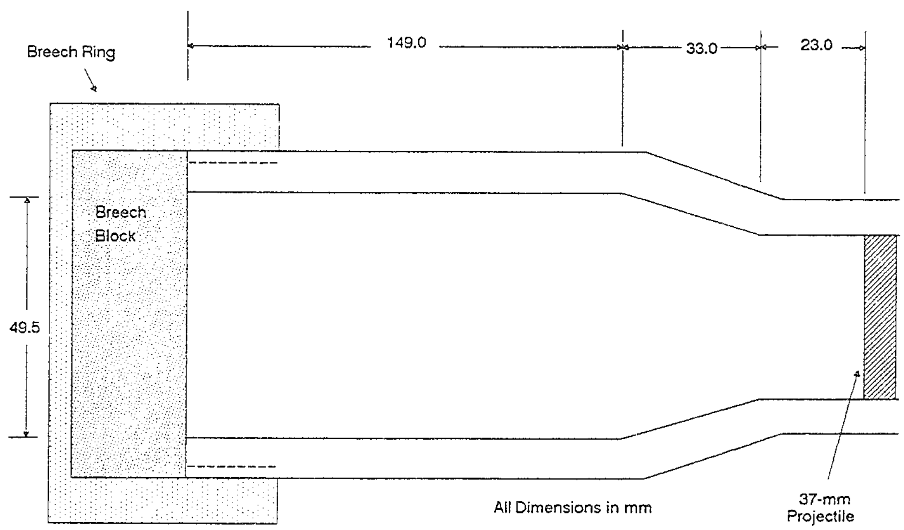

Figure 1. 37-mm Gun Used for Segmented-Chamber BLPG Testing.

3.2 Propellant. OTTO II monopropellant was chosen as the LP for testing. The decision to use OTTO II monopropellant was based on the realization that this propellant is easier to ignite than other candidate propellants (Travis, Knapton, and Morrison 1986) and seems to be less prone to excessive pressures. The thermochemical properties of OTTO II monopropellant are given in Table 1 along with those of XM46, which are included for comparison purposes. It was planned that later tests, pending an evaluation of the tests with OTTO II monopropellant, would be performed with XM46.

Table 1. Properties Of Candidate Liquid Propellants.

LP	Composition			Density (g/cc)	Impetus (J/g)	Flame Temp. (K)	Gamma
	Fuel (%Wt.)	Oxidizer (%Wt.)	Diluent (%Wt.)				
OTTO II	1,2 Dinitroxypropane (76)	Di-N-butyl sebacate (22.5)	2 nitrodiphenylamine (1.5)	1.23	866	1,986	1.266
XM46	TEAN (19.2)	HAN (60.8)	Water (20)	1.43	898	2,469	1.223

3.3 Igniter Three main attributes were identified that an igniter needed to have to be acceptable for our study. The first requirement was that the igniter be one that had been experimentally demonstrated to ignite LP reliably in a medium-caliber BLPG. The second, and most important, was that it should be capable of igniting the LP in each of the subchambers simultaneously. The third, although not a necessity, was that the pressure rise rate be much slower than a traditional BLPG rise rate, yet strong enough to reliably ignite the LP. Knapton and Stobie (1979) had demonstrated the use of a piston radial igniter in effectively igniting NOS-365 propellant. Figure 2 shows a drawing of the piston radial igniter and stub case adapter. The stub case adapter replaces the case base of a standard solid propellant round and is used to house the M52A3B1 electrical primer as well as the piston radial igniter.

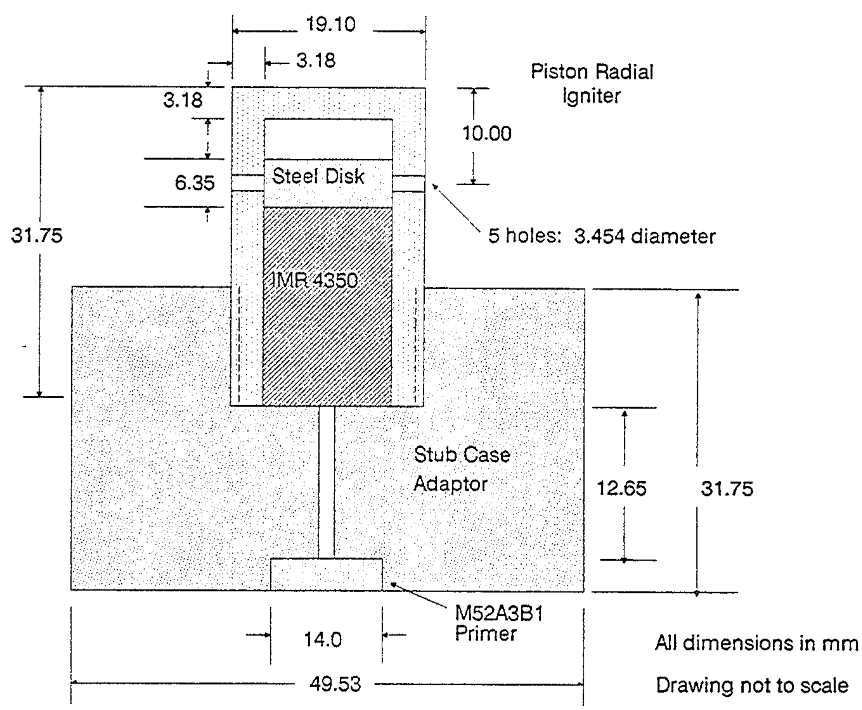

Figure 2. Piston Radial Igniter and Stub Case Adaptor.

Under initial conditions a circular steel disk covered with a silicon rubber sealed each of the five holes in the body of the igniter. IMR 4350 single-perforation solid propellant was loaded into the free volume of the igniter, which was then screwed into the stub case adaptor. Upon initiation of the M52A3B1 electrical primer, the hot gases from the M52A3B1 ignite the IMR 4350. This event forces the steel disk forward, uncovers the igniter vent holes, and simultaneously vents hot gases from the igniter radially into the combustion chamber. The piston radial igniter was chosen over an axial igniter because it was deemed more likely to ignite all the subchambers uniformly. This igniter met all of the criteria outlined previously except for the lower pressure rise rate. The free volume in the igniter, including the vent hole from the M52A3B1 to the IMR 4350, is 2.17 cc before the movement of the piston, and 2.46 cc after the piston has come to rest. Therefore, for loading density calculations in the piston radial igniter, a volume of 2.46 cc was used. Open-air tests were performed, and high-speed photography (7,000 frames per second) was used to demonstrate the uniform venting characteristics of the igniter. Based on these tests, it was felt that the igniter would satisfy the first two requirements outlined previously. The third requirement will be addressed later in this report.

3.4 Chamber Inserts . The manner chosen to effect the chamber segmentation was through the use of nylon chamber inserts (Talley and Owczarczak 1992). Figure 3 shows the three designs used (drawings not to scale). Figure 3a shows a simple cylindrical chamber insert designed to allow baseline testing of a traditional BLPG sytem. The primary purpose of this insert was to provide a baseline for performance comparisons with the segmented-chamber designs and to demonstrate whether segmenting the chamber of a BLPG changed the interior ballistic process. The insert was designed to allow the same propellant volume (29 cc) as the segmented-chamber designs shown in Figures 3b and 3c. Figure 3b shows a simple segmented-chamber design consisting of three holes of equal diameter in the nylon insert. Figure 3c shows a transitioned segmented-chamber design that was angled at the igniter end in an effort to more efficiently couple the igniter gases to each of the subchambers simultaneously.

Figure 4 shows a drawing of the system configuration with the simple cylindrical insert in the chamber. As can be seen in the figure, the insert stops at the chambrage region and does not extend to the base of the projectile. The purpose for this design feature was to ensure a stationary boundary during early combustion and to eliminate the possibility that the insert would be forced down the gun tube during firing. The goal was to impart all of the system

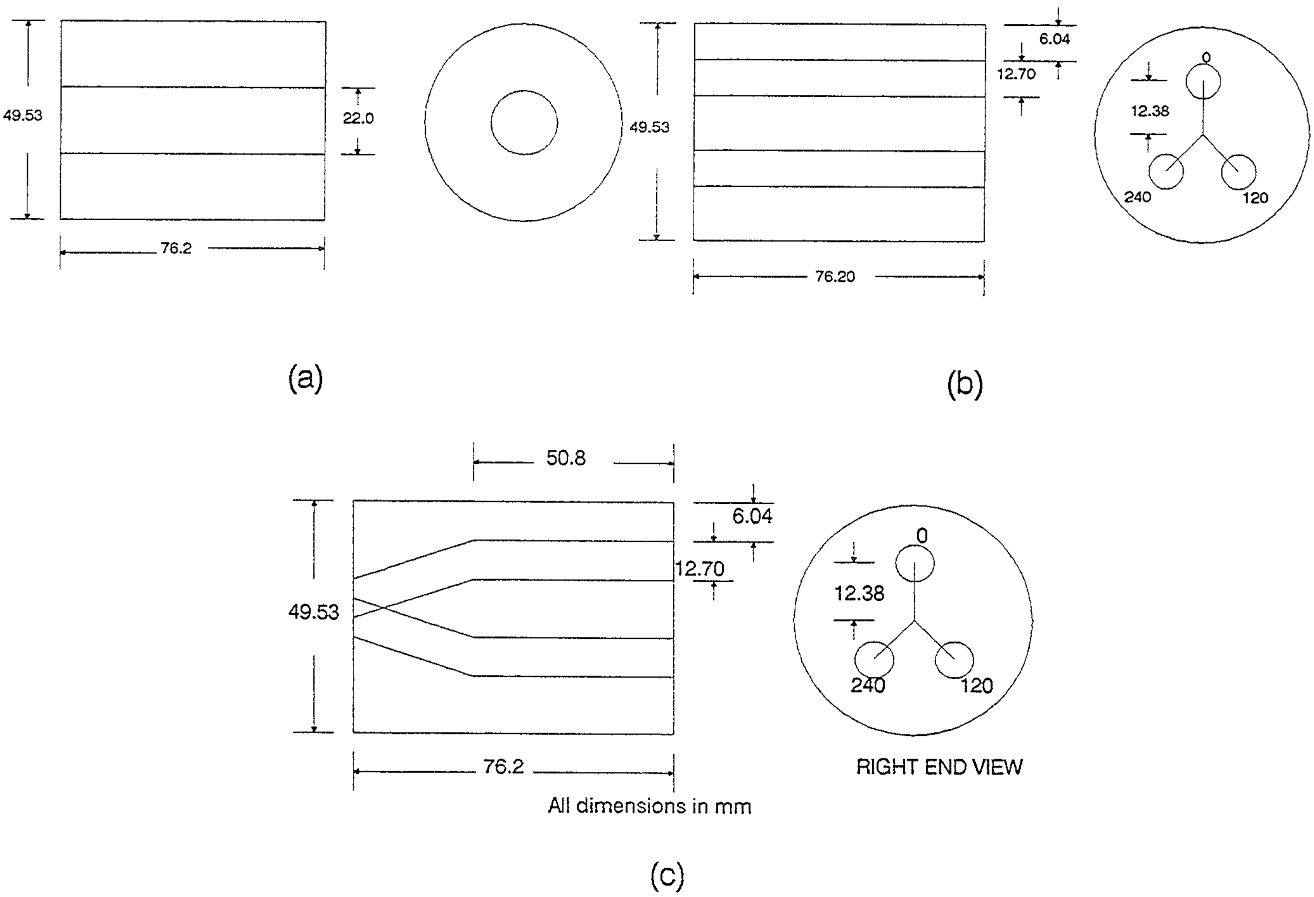

Figure 3. Chamber Insert Configurations. a) Simple Cylindrical Chamber Insert, b) Simple Segmented-Chamber Insert, and c) Transitioned Segmented-Chamber Insert.

energy on the base of the projectile and eliminate any possibility of doing work on the chamber insert. At the igniter end, a practical implication of using a chamber insert to segment the chamber becomes apparent. It appears that one could extend the simple cylindrical chamber insert to the rear of the chamber. However, since the relatively large piston radial igniter would prohibit this with the segmented-chamber inserts, it was not done for the baseline configuration shown. There was a relatively large volume (58 cc) in the rear of the chamber that was empty. It was deemed undesirable to fill this area with LP because of the large step function when transitioning forward into the chamber insert; therefore we needed to fill at least a portion of this volume. In studies performed by Knapton and Stobie (1979) and Knapton et al. (1978), it was demonstrated that placing a Breech Face Insert (BFI) at the rear of the chamber decreased the maximum chamber pressure in 38.8-mm BLPG firings. By placing a BFI at the rear of the chamber, a portion of this volume could be eliminated. However, the size of the BFI was limited by the venting process of the piston radial igniter and only eliminated 10 cc of the free volume, leaving 48 cc of open air volume.

Earlier in this report, three requirements for an igniter were outlined. The first two (reliability and uniform ignition) were addressed at that time and the third was left until now. It was desirable for the early pressure rise rate to be much more gentle than that of a traditional BLPG pressure-time profile. It was expected that if one were to place a donut of solid propellant booster charge in the open volume at the rear of the chamber, the igniter would then vent into solid propellant, providing a much more gentle pressure rise rate and in effect allowing a great deal more control over the early portion of the ballistic cycle. The unknown effect was how well the large solid propellant igniter would couple to the LP charge in the forward portion of the chamber. The insertion of this solid propellant donut into the open air volume in the rear of the chamber proved to be very advantageous. Figure 5 shows the system configuration after the insertion of the BFI and the donut of solid propellant. Note that a paper diaphragm is used to keep the LP contained in the insert and forward chambrage region. The total amount of LP used is approximately 124 cc.

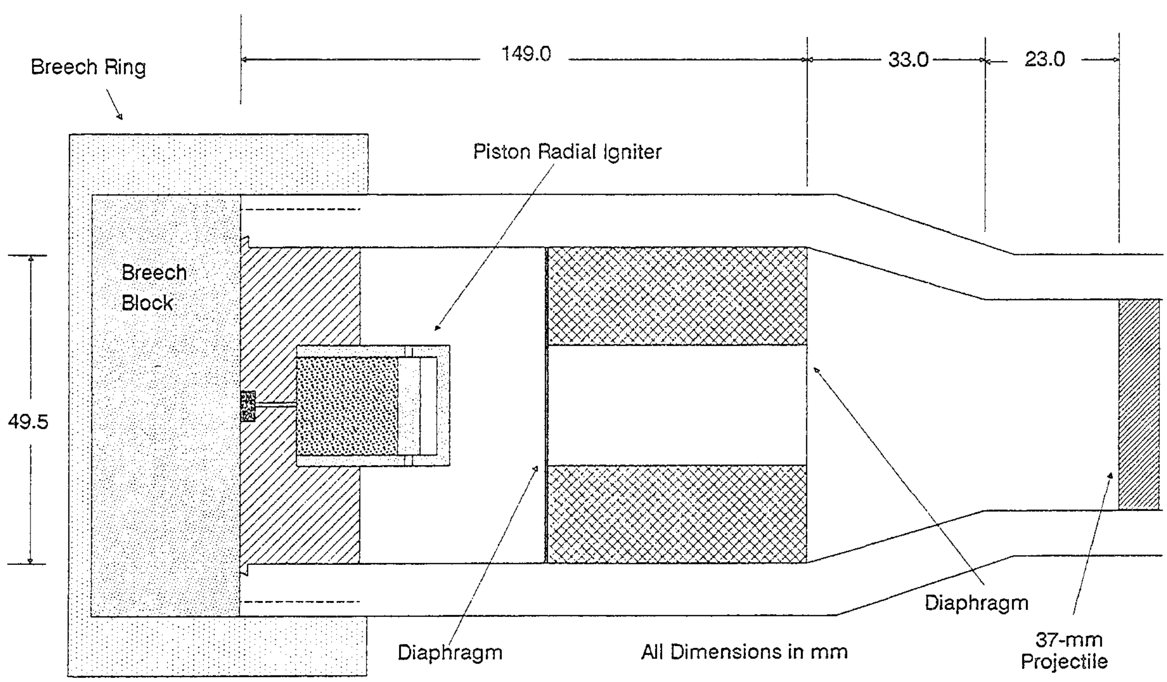

Figure 4. Initial System Configuration.

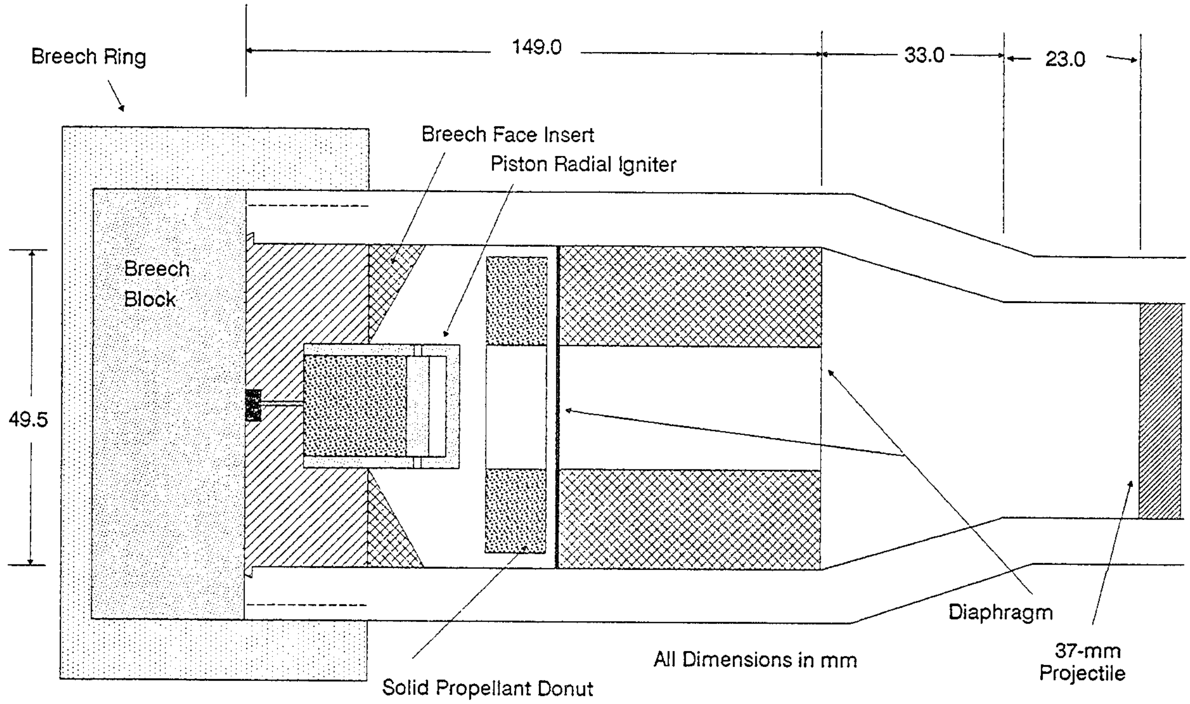

Figure 5. System Configuration After Insertion of Breech Face Insert and Donut of Solid Propellant.

3.5 Instrumentation. Pressure measurements were taken in the fixture using Kistler 607C4 piezoelectric pressure transducers at the locations noted in Figure 6. It was not possible to measure the pressure at the igniter end of the chamber because of the manner in which the breech ring of the weapon attached to the chamber. Pressure ports P1 and P2 were covered by the chamber insert and, subsequently, a hole 3.175 mm in diameter was drilled in the insert and was filled with grease to prohibit LP from leaking out of the insert. P3 was located at the top of the chambrage and was used as the port through which the LP was loaded into the chamber. A syringe was used to inject the LP. As the LP was injected, the air in the chamber was displaced back through the pressure port. Once full, a cotton swab was used to clean excess LP out of the pressure port. A 35-GHz microwave interferometer was used to measure projectile dispacement and processed in real time to obtain a projectile muzzle velocity (Rosenberger and Martz 1992). For each cycle of the interferometer, the projectile moved 4.226 mm. The muzzle velocity was verified using a series of break screens, located 3.5 m to 7.5 m from the muzzle of the gun, and counters to measure the time of projectile passage.

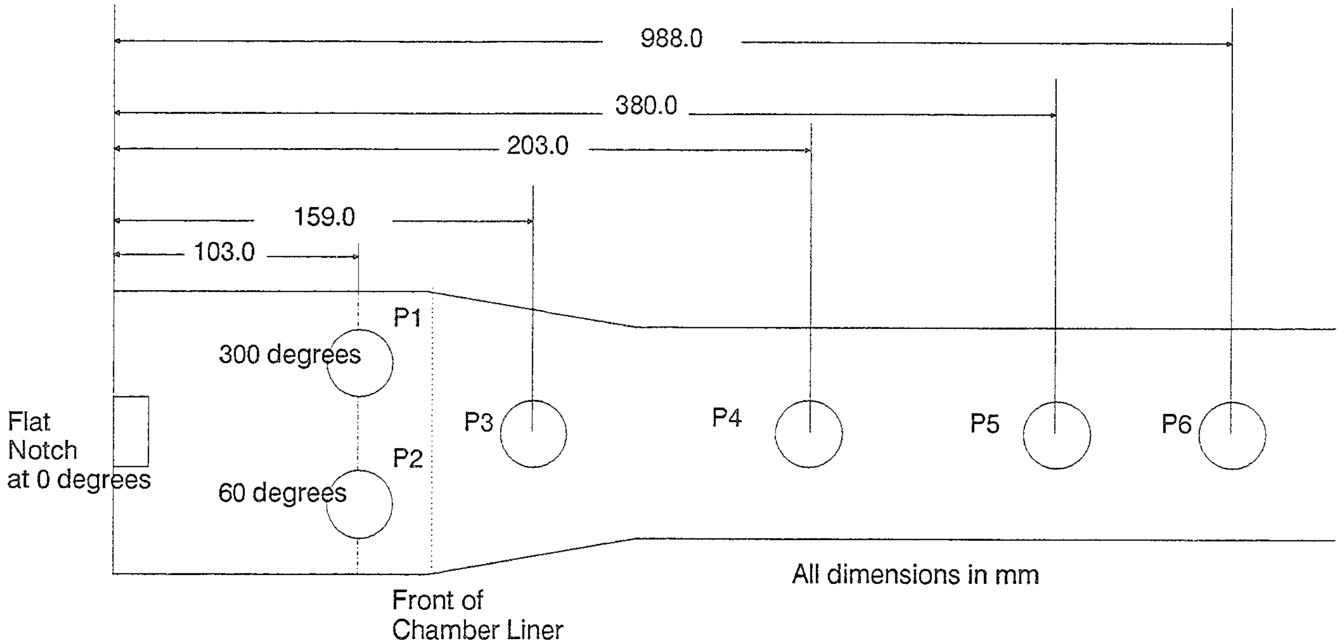

Figure 6. Pressure Transducer Port Locations.

3.6 Simple Cylindrical Chamber Insert Tests. Three rounds were fired using the simple cylindrical chamber insert shown in Figure 3a. System parameters for each of the three rounds are shown in Table 2. The projectile was then loaded into the gun followed by the simple cylindrical chamber insert, which had a paper diaphragm at the igniter end of the insert. LP was then injected into the chamber using a syringe as described earlier. In each case, a bead of silicone sealant was placed around the rotating band of the projectile to act as a low-pressure seal to keep the LP from leaking around the projectile. Once positive assurance of no leaks was obtained by inspecting the rear chamber and the projectile-barrel interface, the solid propellant donut booster charge, BFI, igniter, and stub case were inserted into the chamber and the breech was closed.

Table 2. System Parameters for Simple Cylindrical Chamber Insert Test Series.

Round No.	LP	LP Volume (cc)	LP Mass (g)	Projectile Mass (g)	Propellant Mass in Igniter (g)	Propellant Mass in Booster (g)
5	OTTO II	123	151.3	457	0.8063	15.2
6	OTTO II	123	151.3	457	0.8046	15.2
7	OTTO II	123	151.3	457	0.8077	15.2

Figure 7 shows the pressure-time results from the P3 pressure location (just forward of the insert). As can be seen from the figure, the ignition delays, as referenced from the time the electrical energy is delivered to the M52A3B1 primer, vary as much as 12 ms. However, if the pressure-time curves are plotted without consideration to the ignition delay, as in Figure 8, they overlay quite nicely. The reason for the delay is believed to be the large air volume in the rear of the charge, or the tissue that is used to contain the IMR 4350 solid propellant donut. As can be seen from the figure, the solid propellant, responsible for the initial pressure rise, couples quite well to the LP as is evident by the reproducible rise rate of the pressure-time curves. In addition, the curves exhibit the double hump of a traditional BLPG pressure-time curve; however they appear to be uncharacteristically well behaved. It should be noted here that the double-humped behavior exhibited in BLPGs is typically not repeatable because it is thought that it is generated, at least in part, by Helmholtz mixing and is thought to be responsible for variability in ballistic performance. To gain control of the BLPG ballistic process, it will be neccessary to further understand the genesis and evolution of the double hump. Table 3 shows a performance comparison for the three shot series using the simple cylindrical chamber insert. This series was used as a baseline for comparison with the segmented-chamber tests.

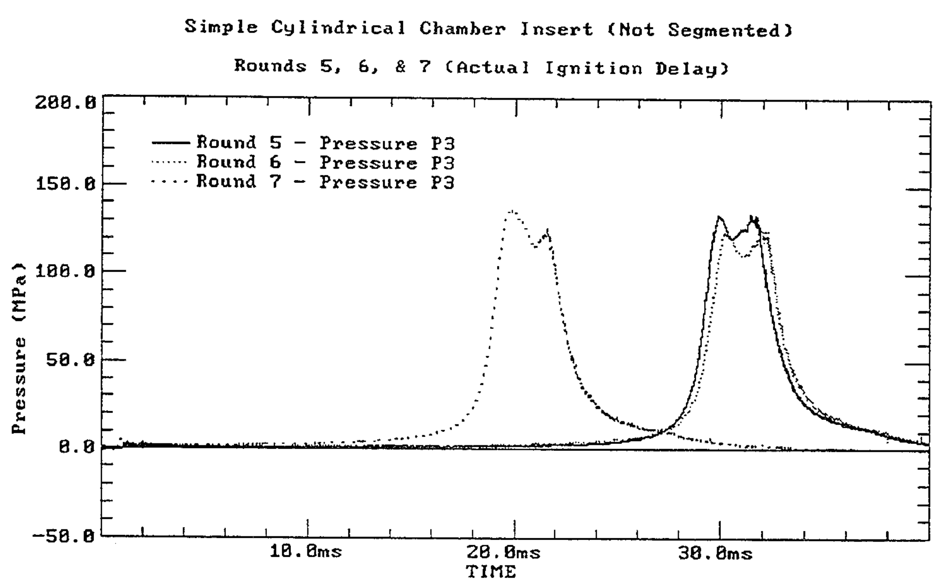

Figure 7. Simple Cylindrical Chamber Insert Test Results.

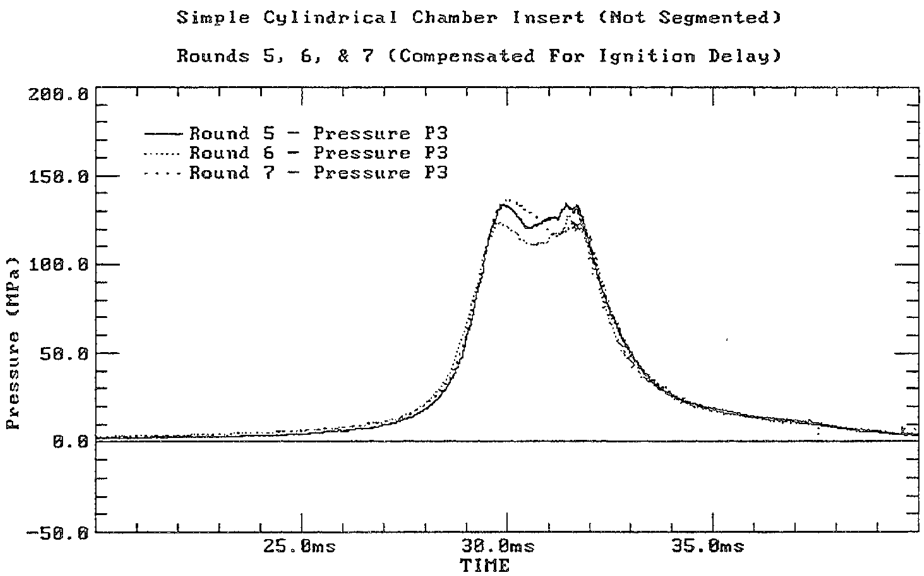

Figure 8. Simple Cylindrical Chamber Insert Test Results Compensated for Ignition Delay.

Table 3. Performance Comparison for Simple Cylindrical Chamber Insert Test Series.

Round No.	Maximum Chamber Pressure - P3 (MPa)	Velocity (m/s)
5	133	800
6	124	778
7	136	801
Average	131	793
Standard Deviation	6.2 (4.8%)	13.0 (1.6%)

3.7 Simple Segmented-Chamber Insert Tests. A total of four rounds were fired using the simple segmented-chamber insert shown in Figure 3b. System parameters for each of the four rounds are shown in Table 4. In each case, both the round and the charge were loaded in exactly the same manner as in the case of the simple cylindrical chamber insert tests. Pressure-time curves for each of the four rounds are shown in Figure 9. As can be seen from the figure, Round 09 was an outlier that displayed not only a much longer ignition delay, but also evidence of a higher chamber pressure. There was evidence of a possible leak in the chamber upon inspection of the fixture after the test, but no conclusive reason could be found to explain the results. However, if we again plot the pressure-time curves without consideration for the time delay, the early portion of the curves overlay, including the outlier, as shown in Figure 10. If we eliminate Round 09, the curves overlay reasonably well up to maximum pressure as shown in Figure 11. Another important feature that the plots exhibit is that the shape of the curve at peak pressure is slightly different from that of the simple cylindrical chamber insert tests. The segmented-chamber insert has had the effect of lessening the degree of the double hump at peak pressure. As seen in Table 5, the performance parameters compare fairly well for a nonoptimized system, except for Round 09. When comparing the performance data to that of the simple cylindrical chamber firings shown in Table 3, the performance of the two systems is nominally the same.

Table 4. System Parameters for Simple Segmented-Chamber Insert Test Series.

Round No.	LP	LP Volume (cc)	LP Mass (g)	Projectile Mass (g)	Propellant Mass in Igniter (g)	Propellant Mass in Booster (g)
8	OTTO II	124	152.5	457	0.7996	15.2
9	OTTO II	127	156.2	457	0.8005	15.2
10	OTTO II	128	157.4	457	0.8016	15.2
11	OTTO II	120	147.6	457	0.8036	15.2

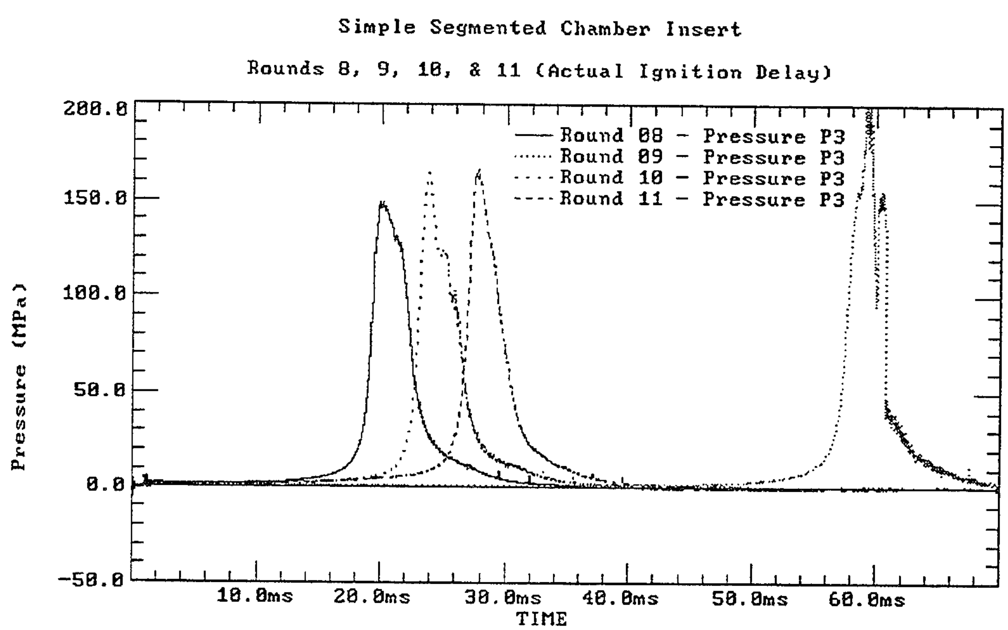

Figure 9. Simple Segmented-Chamber Insert Test Results.

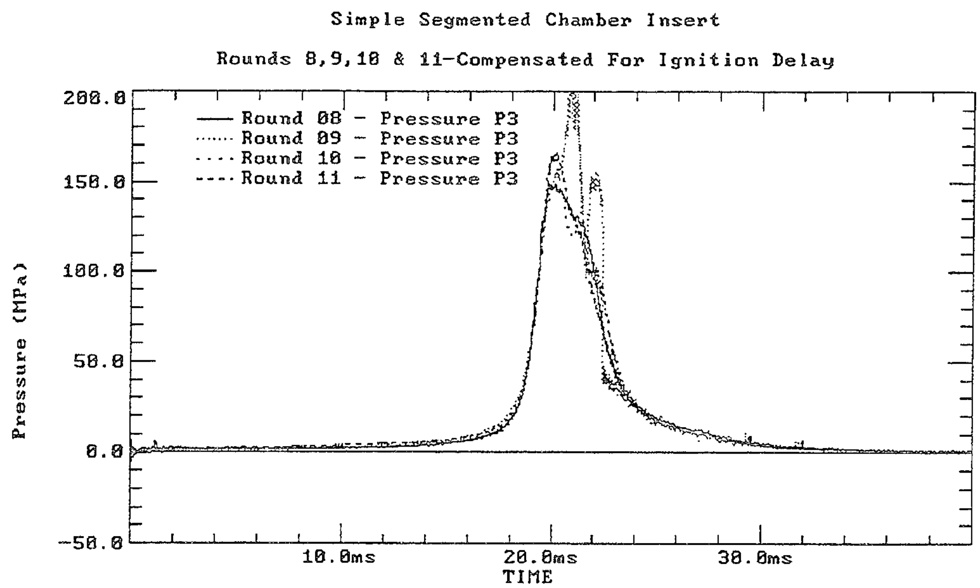

Figure 10. Simple Segmented-Chamber Insert Test Results Compensated for Ignition Delay.

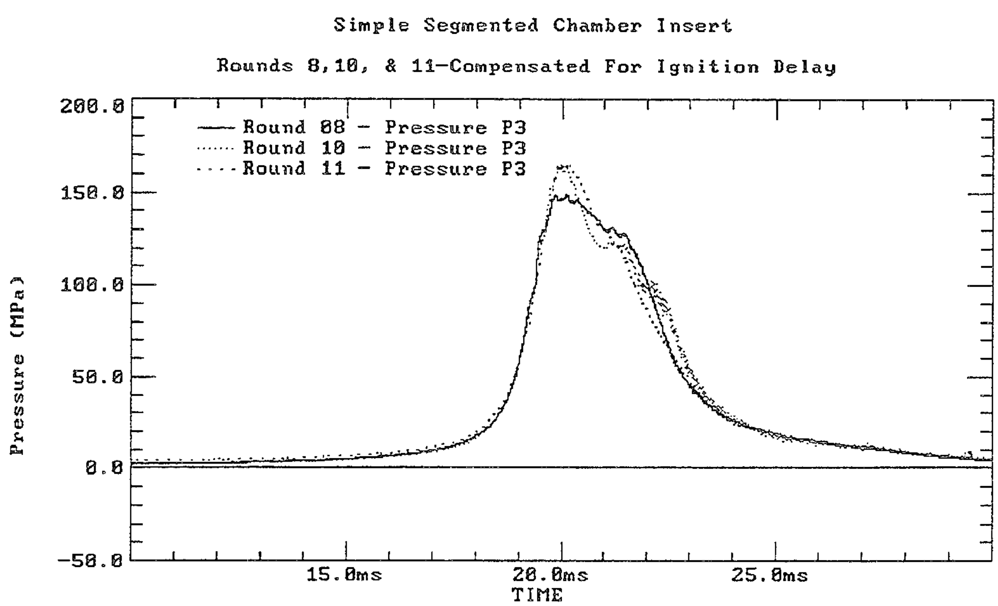

Figure 11. Simple Segmented-Chamber Insert Test Results Compensated for Ignition Delay Plotted Without Round 9.

Table 5. Performance Comparison for Simple Segmented-Chamber Insert Test Series.

Round No.	Maximum Chamber Pressure - P3 (MPa)	Velocity (m/s)
8	148	811
9	198	835
10	164	821
11	165	806
Average (8,9,10,11)	169	818
Standard Deviation (8,9,10,11)	21.0 (12.4%)	12.8 (1.6%)
Average (8,10,11)	159	813
Standard Deviation (8,10,11)	9.5 (6.0%)	7.6 (0.9%)

3.8 Transitioned Segmented-Chamber Insert Tests. Three rounds were fired using the transitioned segmented-chamber insert shown in Figure 3c. The subchambers were angled at the igniter end in an effort to more closely couple the igniter gases to each of the subchambers. System parameters for each of the three rounds are shown in Table 6. In each case, both the round and the charge were loaded in exactly the same manner as in the case of the previous two test series. Figure 12 shows the pressure-time curves for each of the three rounds. Once again, the ignition delay varies by the same magnitude as previous designs. As expected, when the pressure-time curves are plotted without consideration for the time delay, the early portions of the curves overlay as shown in Figure 13. Another important feature that the plots exhibit is that the shape of the curve at the peak is again slightly different than that of both the simple cylindrical chamber insert tests and the simple segmented-chamber insert tests. The transitioned segmented chamber insert has had the effect of nearly eliminating the double hump at peak pressure. As seen in Table 7, the performance parameters compare fairly well for a nonoptimized system. When comparing the performance data to that of the simple cylindrical chamber insert firings shown in Table 3, and to those of the simple segmented-chamber insert firings shown in Table 5, the performance is again nominally the same.

Table 6. System Parameters for Transitioned Segmented-Chamber Insert Test Series.

Round No.	LP	LP Volume (cc)	LP Mass (g)	Projectile Mass (g)	Propellant Mass in Igniter (g)	Propellant Mass in Booster (g)
12	OTTO II	121	148.2	457	0.8016	15.2
13	OTTO II	124	152.5	457	0.8060	15.2
14	OTTO II	123	151.3	457	0.8033	15.2

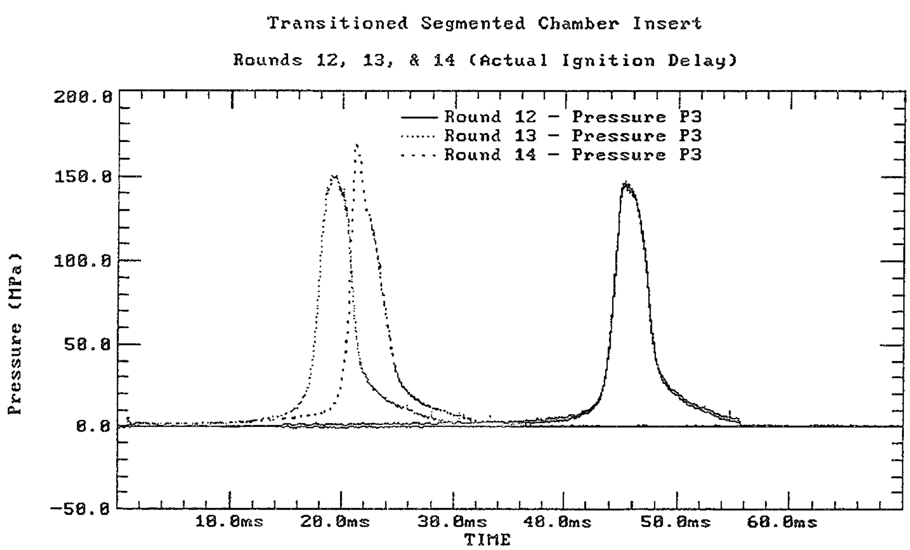

Figure 12. Transitioned Segmented-Chamber Test Results.

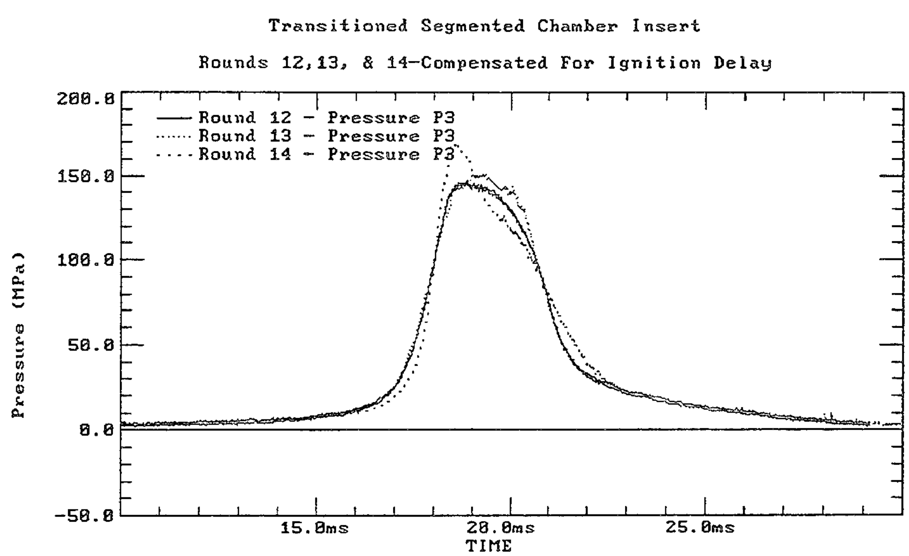

Figure 13. Transitioned Segmented-Chamber Test Results Compensated for Ignition Delay.

Table 7. Performance Comparison for Transitioned Segmented-Chamber Insert Test Series.

Round No.	Maximum Chamber Pressure - P3 (MPa)	Velocity (m/s)
12	146	758
13	150	818
14	169	809
Average	155	795
Standard Deviation	12.3 (7.9%)	32.6 (4.0%)

In each of the three configurations presented here, the coupling of the solid propellant to the LP was very smooth, and the subsequent rise to peak pressure compares quite well in all cases. As shown in Figure 14, the main difference in the pressure-time curve from one configuration to the next occurs at peak pressure. The simple cylindrical chamber configuration, the classical BLPG baseline, exhibited the classical double-humped pressure-time trace. The simple segmented configuration exhibited less of a double-humped pressure-time curve. In the case of the transitioned segmented configuration, the double-humped pressure-time curve was almost eliminated.

The reason for the variance in the pressure-time curve from one configuration to the next may prove critical to understanding the BLPG process. One possible explanation is that segmenting only the middle of the chamber allowed the segmented portion to act as a very high-pressure igniter. In each configuration, the volume in the nylon chamber insert was kept approximately the same. If one calculates the volume opened up behind the projectile due to the initial projectile travel up to the time of peak pressure (through the use of the microwave interferometer), it is about the same as the volume of the nylon chamber insert. It is speculated that a portion of the LP was ignited before the igniter gas plume blew through into the forward area of the chamber; which was the same configuration as the classic BLPG case. At this time, there is a slight drop in pressure due to the increased volume vacated by the projectile. Mixing occurrs which is robust enough to smoothly burn the remainder of the LP. In the case of the segmented-chamber configurations, the propellant in the chamber insert burns more uniformly and initiates better mixing as the three high-pressure plumes blow into the forward portion of the chamber; resulting in a smoother pressure-time curve.

At this time not much more can be said concerning the effectiveness of the concept in controlling the ballistic variability in BLPGs. Based on the previous explanation, it is felt that by segmenting the entire chamber, more control could be achieved by eliminating the classical BLPG configuration in the forward portion of the chamber. It is evident from the consistency in the pressure-time curves to near-peak pressure that the solid propellant igniter allows a great deal of control and repeatability of the early combustion event. However, this does not assure repeatable ballistics based on the pressure-time curves later in the combustion process and the performance comparisons presented here. This supports an earlier postulate that repeatability of the igniter is a neccessary, but not a sufficient condition to ensure stable ballistics (Knapton and Stobie 1979; Knapton et al. 1978).

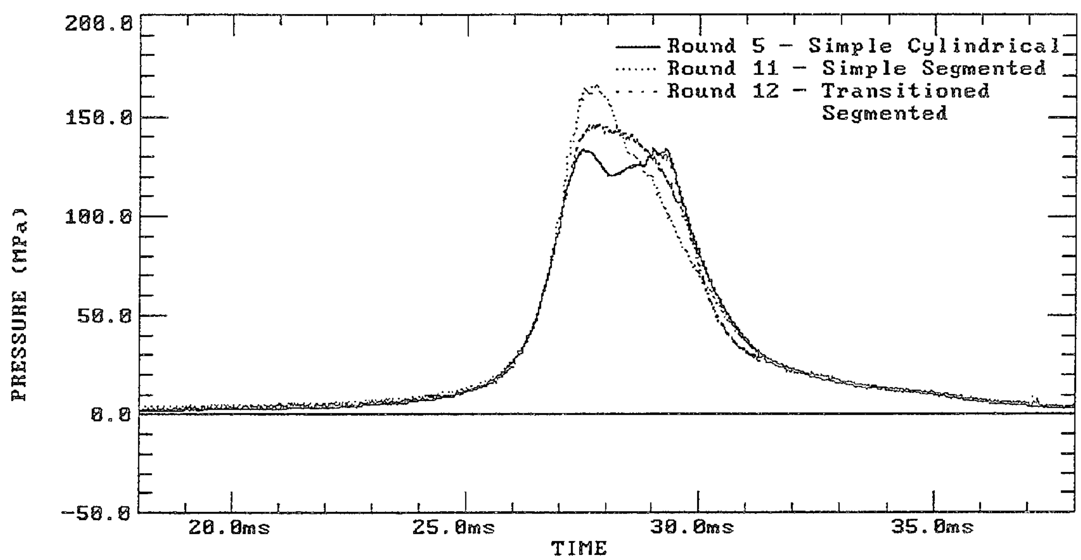

Figure 14. Comparison of Pressure-Time Histories for Simple Cylindrical, Simple Segmented, and Transitioned Segmented-Chamber Inserts.

3.9 XM46 Propellant Tests. The series of tests performed using OTTO II monopropellant demonstrated that segmenting the combustion chamber of a BLPG had noticeable effects on the ballistic process and that a reasonable level of control of the combustion process was achieved up to maximum pressure. Based on these rather encouraging results, we decided to evaluate the effects of the segmented-chamber concept using the HAN-based propellant XM46. As previously stated, XM46 has been demonstrated to be more difficult to ignite than OTTO II monopropellant and there was a great deal of concern that this would cause problems with demonstrating the effectiveness of this system in XM46. The system configuration shown in Figure 5 was used with the simple cylindrical chamber insert to act as a baseline for future testing. Figure 15 shows the chamber pressure and microwave interferometer from this test.

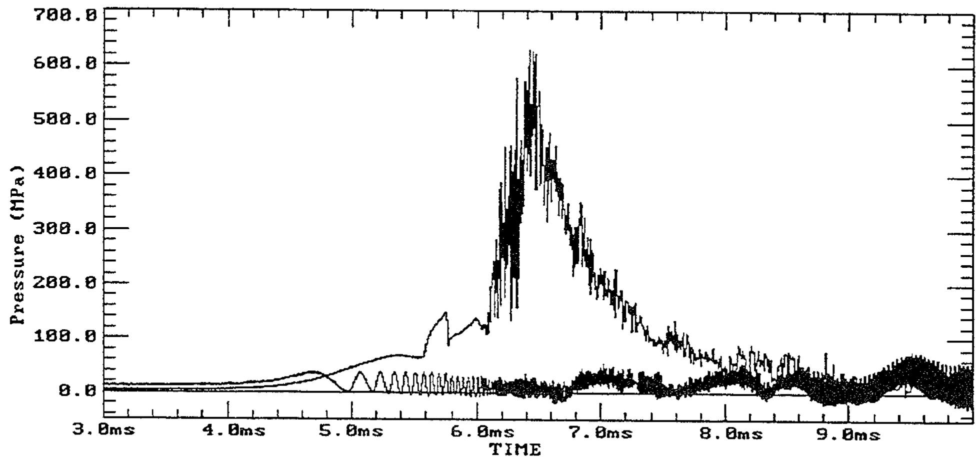

Figure 15. Example of Poor Ignition of XM46 in a BLPG.

As suspected, the ballistic process proved to be drastically different. The early pressure rise up to 20 - 30 MPa agrees quite well with that of earlier testing. However, XM46 proved much more difficult to ignite. As the pressure increased to about 60 MPa, a change in slope can be observed as if some amount of LP begins to burn. However, the pressure drops soon after increasing, suggesting either a lack of sustained combustion or that the gas generation rate can not keep up with the increasing volume caused by projectile motion. The sharp pressure excursion at about 5.7 ms is likely an artifact of the pressure measurement. As the LP blows through into the forward portion of the combustion chamber, mixing is not robust enough initially to burn the remainder of the propellant (5.6 ms - 6 ms). As mixing continues with undefined burning surface area, the condition required for the remainder of the bulk-loaded charge to ignite is reached, and it rapidly ignites. As in past bulk liquid propellant programs, the condition needed to initiate the XM46 in a controlled manner is not known. This test was repeated with similar results. Investigations are ongoing into system modifications to ignite XM46 in a controlled manner and maintain more stable ballistics.

The fact that the system configuration used quite successfully with OTTO II monopropellant does not exhibit stable ballistics when using XM46 is, to say the least, very interesting. In light of the very different chemical compositions of the two propellants, this may suggest that chemical kinetics plays a major role in the bulk-loaded LP burn process. At this time, this is only an observation, and nothing more can be said about the importance of chemical kinetics in bulk-loaded LP processes versus the role that hydrodynamics may play relative to the generation of surface area and subsequent gas generation rates.

The importance of an appropriate ignition system to the bulk-loaded LP process is well documented in literature. The data presented here support this assertion. Interestingly, recent work by Talley and Owczarczak (1992) at Veritay Technology Incorporated has shown that there is not much difference in the ballistics for a 20-mm BLPG gun firing using OTTO II monopropellant and for a 20-mm BLPG gun firing using XM46. Figure 16 shows a comparison of chamber pressure histories for a 20-mm BLPG firing using OTTO II monopropellant and XM46, respectively. Both tests were fired under the same system configuration using an axial igniter. For the most part, the two curves exhibit very similar behavior, unlike the data presented in this report for the two different propellants. These data, contrary to our tests, do not support the assertion that chemical kinetics plays a major role in the bulk-loaded LP burn process of a 20-mm BLPG. It is evident, however, that system parameters such as chamber volume, chamber L/D, and ignition configuration are key parameters for controlling the BLPG ignition and combustion processes.

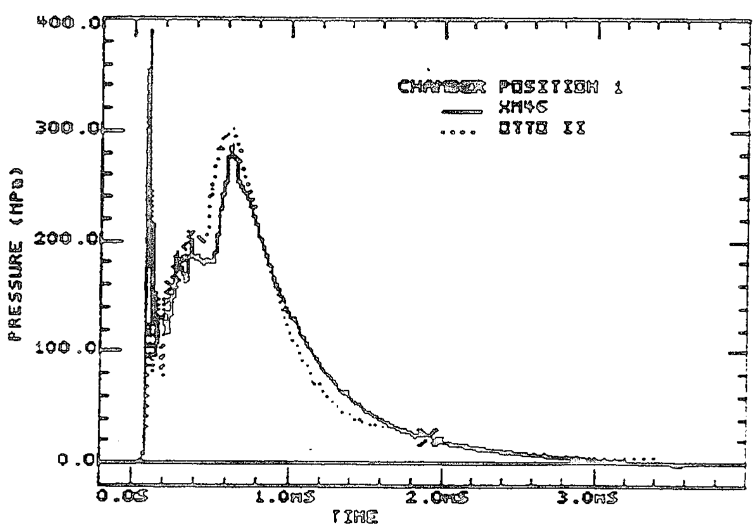

Figure 16. Comparison of Pressure-Time Histories for a 20-mm BLPG Using OTTO II Monopropellant and XM46.

4. CONCLUSIONS

Based on the experimental data presented here, it is evident that segmenting the combustion chamber changed the combustion evolution of the 37-mm BLPG system when OTTO II monopropellant was used. The performance comparisons presented here show consistency on a shot-to-shot basis within a particular series. The pressure-time histories are reasonably well behaved for a nonoptimized system. Subsequent tests designed to investigate the feasibility of achieving the same result using XM46 indicated that XM46 is more difficult to ignite and therefore did not exhibit the same ballistic results. Data were presented which demonstrated comparable ballistic results when using OTTO II monopropellant and XM46 in a 20-mm BLPG ignited by an axial igniter. It was asserted that chemical kinetics may play a major role in the bulk-loaded LP burn process of the 37-mm BLPG system investigated. However, this does not agree with test results from the 20-mm BLPG configuration used by Talley and Owczarczak (1992) at Veritay Technology Incorporated.

Future testing in segmented-chamber BLPG technology will be continued at the ARL. The emphasis will be in the transition of the successful approaches presented here for OTTO II monopropellant to a system using XM46. Further, segmentation of the entire combustion chamber will be effected in an effort to control the ballistic process. A high-pressure fixture is being built to facilitate BLPG firings without the constraints of a restricted pressure envelope. Future tests will involve decreasing the size of the solid propellant booster, using faster burning solid propellants and higher igniter loading densities, to effect the segmented-chamber approach in a medium-caliber system using XM46. Alternative segmented-chamber configurations will also be explored.

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